October 2002 • NREL/SR-560-32540

Subcontractor Report

# Development of a Fully Integrated PV System for Residential Applications

## PVMaT5a Final Report
## December 18, 2001

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National Renewable Energy Laboratory

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Prepared under Subcontract No. ZAX-8-17647-02

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## ABSTRACT

The primary objective of this program is to develop a readily manufacturable product that will increase US domestic PV power system production and installed capacity, by reducing the total installed cost and increasing the reliability of residential rooftop mounted PV power systems.

To reach this goal, Utility Power Group (UPG), a wholly owned subsidiary of Kyocera Solar, Inc. and Xantrex Technology Inc. have designed, assembled, and tested a new photovoltaic (PV) power system for residential rooftops. This system will offer grid support rooftop PV systems at a reduced cost to the consumer, with improved reliability, as well as the option of battery backup for their residential power.

A new PV array system has been developed, which is pre-fabricated in a factory and installed on the residential rooftop using standard metal parts. This PV array design and installation process is suitable to be adapted to a new product line of PV installation kits for retail purchase.

- At the time of this writing, over 80 of the new PV arrays have been built and installed on rooftops in the greater Sacramento metropolitan area.
- The direct material and labor cost of the array installation has been reduced from a previous average cost of $7.00 per square foot, to as low as $3.79 per square foot for a 2400W installation.

To complement this new PV array, a modular, maintenance free, battery-based, Power Unit and Energy Storage Unit have been developed. Together, these components comprise a system that will enable the residential grid-tied customer to easily select and purchase the installation of a rooftop PV power system, and to have the optional added benefit of back-up power. The design, fabrication, and testing have been completed for two prototypes of this system. These products have been evaluated for their structural integrity, electrical performance, reliability, cost, and manufacturability.

- A Power Unit has been developed and two prototypes have been manufactured. Performance data taken on these units demonstrates a full power conversion efficiency of 96%, up from the 85% typical for models commercially available today.
- The direct material and labor cost of the Power Unit has been reduced from $0.67 per watt in similar units, to $0.34 per watt.
- The Energy Storage Unit (ESU) has been UL listed. This unit utilizes Valve Regulated Lead Acid batteries and has a total energy storage capacity of 13 kilowatt-hours.

The Power Unit and the ESU development have proceeded through the prototype stages. Software development has lagged behind the hardware production, and these units have been operated with the use of a reduced set of control functions in order to evaluate the hardware performance.  The power storage and energy conversion processes are within the goals of this subcontract, however, they are unable to perform the complex control functions required for a complete hybrid PV system.

The success of the new modular, prefabricated PV Array System has been through the implementation of this array in systems utilizing a simple, commercially available grid-tie inverter.

## EXECUTIVE SUMMARY

Research under Phase 5A of the Photovoltaic Manufacturing Technology (PVMaT) project addresses PV system and component technology. During this phase 5A1 subcontract, Utility Power Group (UPG), a wholly owned subsidiary of Kyocera Solar, Inc. and Xantrex Technology Inc. have developed an innovative integrated, low-cost residential photovoltaic (PV) power system with an energy storage capability.

### SUBCONTRACT OBJECTIVES

The primary objective of this program has been to develop the technology and manufacturing capability to produce the integrated residential PV system. The result of this objective is to increase US domestic PV power system production and installed capacity, by reducing the total installed cost and increasing the reliability of residential rooftop mounted PV power systems.

The cost of a photovoltaic generation system may be divided into two categories: the cost of the PV modules, and the balance-of-system (BOS) cost. This project addresses a way to reduce the BOS cost by:

- Standardizing the design.
- Simplifying the design of the system for plug and play operation.
- Improving the power conversion efficiency of the system.
- Reducing on-site installation labor.
- Increasing the production volume.

The new PV power system has been developed to address BOS costs for a residential rooftop system consisting of 3 components:

- PV Array: All PV modules (either crystalline or thin-film), panels, structural support equipment and materials, DC electrical equipment and materials, and installation labor and equipment required to secure the rooftop PV array and make the required electrical connections from the array to the Power Unit.
- Power Unit: All materials, components, and equipment required to perform all AC and DC power connection, conversion, inversion, and control functions. Serves as the interface from the PV array to the household utility service, and includes the interface to the optional Energy Storage Unit, when used.
- Energy Storage Unit (ESU): A set of batteries and all structural, mechanical, electrical, and electronic equipment required to provide a source of on-site stored energy. The ESU is optional equipment that may be connected to the power unit to enable the back-up power feature for operation of critical loads during utility line service interruption.

The financial goal is to achieve a 30% reduction in total BOS system costs by reaching the following individual goals:

- PV Array: Less than \$4.00 per square foot (exclusive of the PV module cost).
- Power Unit: Less than \$0.45 per watt.

## OUTCOMES

UPG and Xantrex have completed design, fabrication, and testing on the first higher voltage, modular, maintenance free, battery-based, fully integrated PV system for residential applications. They have thus created a residential rooftop generation system which requires less engineering for site-specific applications and less time to install, and which also provides the option of on-site energy storage while costing less than the equivalent custom PV systems that are commercially available.

Specific economic goals have been established and have been met:

- PV Array Installation Costs: The material and direct labor cost of installing the PV array has been reduced from \$7.00 to as low as \$3.79 per square foot.
- Power Unit Production Costs: The material and direct labor cost of producing the Power Unit has been reduced from \$0.67 for similar models, to \$0.34 per Watt.

The performance goal for the Power Unit, operating with Energy Storage Unit, was to achieve a conversion efficiency of greater than 94% at full rated output power, with total harmonic distortion below 5%. The Power Unit design has exceeded this goal:

- Efficiency increased to 96% at power levels of 30% to 100% of rated output power.
- Total harmonic distortion reduced to 0.9% at full rated load.

## CONCLUSIONS

- Over 80 residential rooftops have been equipped with the modular PV rooftop array designs and installation processes.
- A Power Unit with exceptionally high efficiency and low distortion has been developed.
- A PV system with battery backup power during utility line outages has been presented. This system will provide back-up power to the residential customer in times of utility grid interruption.

A new, modular PV array has been developed to be pre-fabricated in a factory and installed on the residential rooftop using standard metal parts. This improvement reduces the cost of the PV array support structure and reduces the on-site installation time.

A new Power Unit and Energy Storage Unit have been built and tested, and have met the technical goals set forth. They provide an affordable, efficient, and reliable residential PV power source.

This program has advanced US domestic PV system production and installation capacity and set the stage for future development of even more commercially viable PV power systems:

# 1. INTRODUCTION

Utility Power Group (UPG), a wholly owned subsidiary of Kyocera Solar, Inc. and Xantrex Technology Inc. entered into this subcontract to create a residential rooftop generation system to be largely prefabricated in a factory environment, and which also provides the option of on-site energy storage for operation of critical loads during utility line service interruption. This approach increases factory output, while reducing the engineering and installation time for site-specific applications, and costing less than the equivalent custom PV systems.

There are a great many potential customers for this equipment. The majority of these have opted to delay or discontinue their interest of investing in a residential rooftop PV generation system. The initial investment cost is prohibitive for many. For others, the complexity of engineering and design of the system for their application is daunting. Of the remaining potential customers, some are discouraged to learn that they will have no enhanced continuity of service because utility-interactive PV systems do not operate when the utility line service is interrupted unless the high cost of energy storage is included.

Solar power installations for residential rooftops have several drawbacks that limit their appeal to consumers and have thus restricted their application.

- The initial investment cost is very high.
- Custom system design and engineering is required for each installation.
- System inefficiency reduces actual power output.
- On-site storage is seldom made available in grid-support applications.

These obstacles must be overcome before residential rooftop photovoltaic (PV) generation may be fully developed as a renewable energy technology for on-site electrical generation and storage.

This report summarizes the work performed by UPG and Xantrex to address these obstacles, and how the installation of residential rooftop generation has increased as a result. Also discussed is what future steps may be taken to further enhance the goal of improving the reliability and increasing the capacity of US residential rooftop PV electricity generation.

UPG and Xantrex have performed design, testing, and production readiness of the components of a new residential PV system incorporating energy storage as detailed herein.

## 1.1. BACKGROUND

The product development and the manufacturing environment improvements for the equipment developed under this subcontract have been shared by UPG and Xantrex. UPG has concentrated on the PV Array Development and Optimization. Xantrex has contributed the development and optimization of the Power Unit and the Energy Storage Unit (ESU).

## 1.2. TECHNOLOGY CONCEPT

For the PV Array component, UPG has created a method of panelizing and pre-wiring PV modules as a factory assembled unit. The panels are then mounted on the residential roof by use of a set of standardized components manufactured from commercially available steel shapes. The cost to install this system is lower than that of a typical custom-designed, built-in-place residential rooftop PV system.

The Power Unit designed by Xantrex enhances overall system performance by the use of a higher voltage energy storage system. Common inverters manufactured for use with batteries are limited to a nominal operating voltage of 48 Volts DC. The Xantrex solution enables the use of supply battery voltages of 450 Volts DC. Higher voltage energy storage allows direct DC to AC power conversion without the relatively high losses of the voltage "boost" stage required with low voltage storage systems. Additionally, the higher voltage energy storage source (batteries) provides for excellent transient response for excellent operation during the output load surges typical of motor-driven household appliances, such as refrigerators.

Energy storage for this system is performed within the ESU by the use of a bank of Valve-Regulated Lead-Acid (VRLA) batteries, a charge balance circuit, and an integrated environmental enclosure. VRLA batteries offer advantages over other commercially available batteries, however their stringent charge cycle demands require the implementation of the innovative Active Charge Control circuitry.

In all PV systems, some power is lost, or dissipated, during the necessary power conversions from the PV to the AC line. This is expressed as efficiency; the higher the efficiency, the lower the power losses. The higher operational voltage of the PV power generation system developed under this sub-contract minimizes power loss at every stage.

Additionally, there is some distortion in the AC output due to the conversion process. This is expressed as Total Harmonic Distortion (THD); the lower the THD, the better the performance. The Power Unit and Energy Storage Units have been designed to have the highest efficiency and the lowest THD commercially available.

## 1.3. PROJECT APPROACH

This program has been organized into seven tasks involving the three elements of the design. Goals and objectives have been laid out in order to monitor and evaluate the results of this program.

### TASK 1. PV ARRAY DEVELOPMENT

The development of a structural interface between the PV array and the roof, and the electrical connection between PV modules was completed. A modular system with custom manufactured metal framing members was devised to reduce the installation complexity of the PV system. Two such systems were deployed (Figures 1 and 2).

The goal of this initial deployment was to demonstrate the effectiveness of a modular, pre-manufactured PV array in reducing the time required and total costs for design and installation of a rooftop PV system.

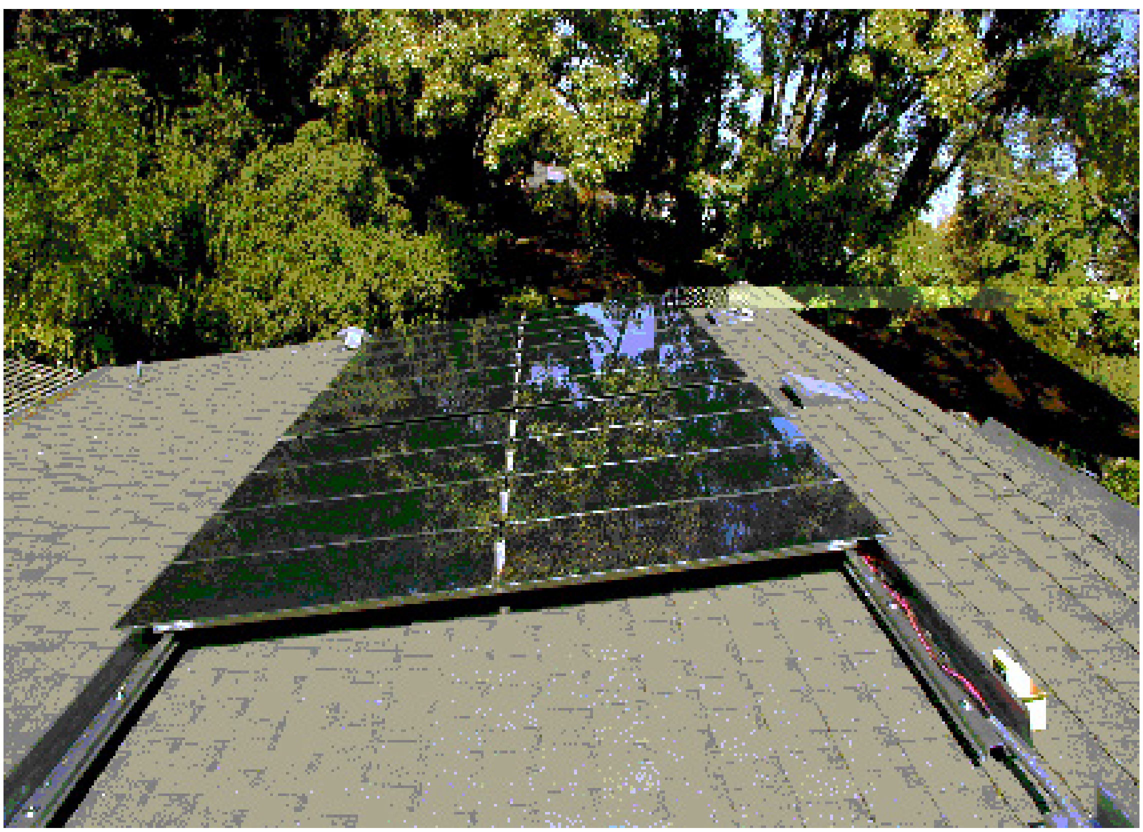

**Figure 1. First Prototype Array, Under Construction**

The PV panels were assembled within a factory environment. A two-module panel configuration was designed to minimize the cost of assembly labor and handling. During the PV panel assembly process, modules could be configured with parallel or series wiring to accommodate high or low voltages for different inverter applications. Note the incorporation of the array wiring into the support structure.

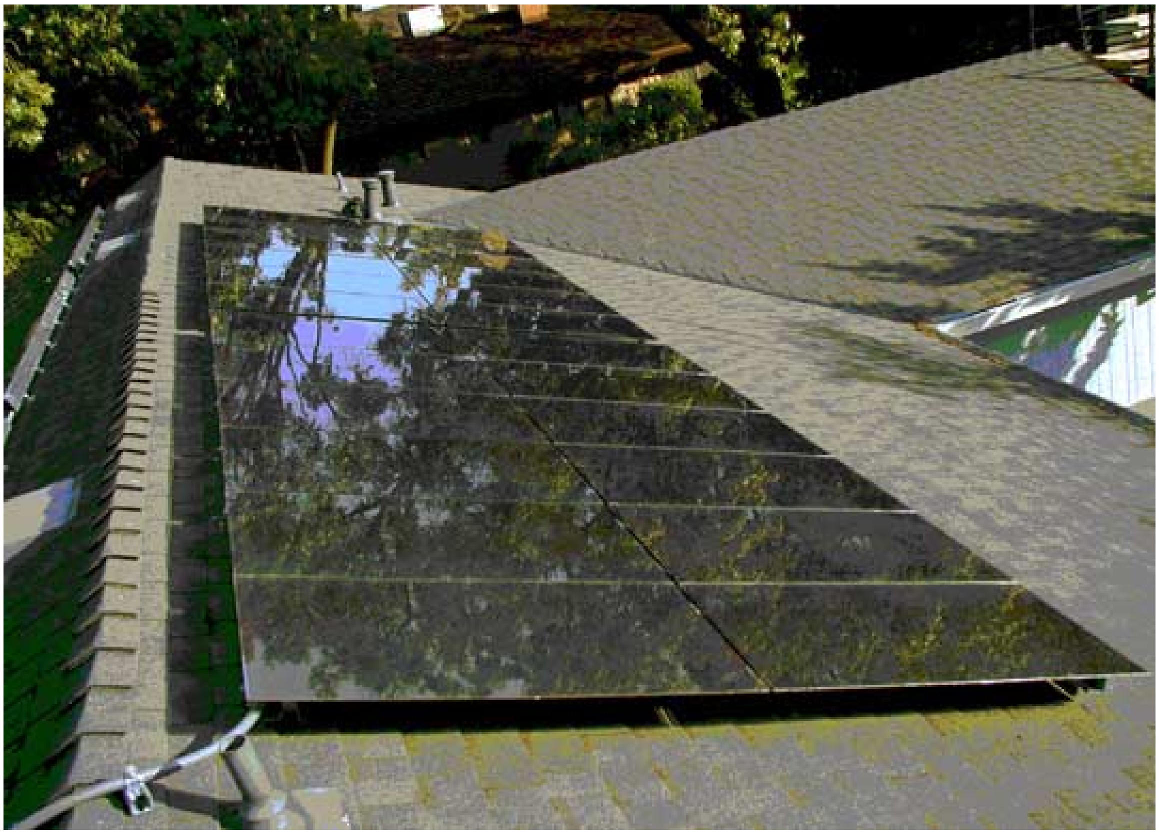

**Figure 2. First Prototype Array**

The first prototype PV array installation, shown in Figure 2, was based on the UPG / KSI patent #6,065,255. This array encompassed approximately 90% custom fabricated galvanized sheet and stainless steel materials. The goal of this type of design was to off-set the cost of fabricated materials with volume of fabrication and simplicity of assembly, thus reducing the cost of field labor for the array installation process.

The structural interface was then refined under *Task 2.4, PV Array Optimization*, in order to meet the final cost goal of $4.50 for the direct materials and installation labor of the PV array.

## TASKS 2 AND 5. POWER UNIT DEVELOPMENT AND OPTIMIZATION

A design was developed for a highly reliable Power Unit that would deliver up to 12kW of low distortion power divided equally into each phase of a 120/240 Volt split-phase residential power system. Efficiency was predicted to be above 95% over a wide power range, so that more of the energy generated by the PV would be utilized. This power unit was designed with an option to operate in conjunction with an energy storage unit, for household back-up power in the case of utility grid interruption.

These products were developed as primary components of a fully integrated PV system for residential applications in order to:

- Achieve total system cost reductions.
- Provide higher system reliability.
- Increase system power conversion efficiencies.

Two Power Unit prototypes were produced and tested. The innovative packaging of the Power Unit was designed for outdoor deployment, ease of installation, and user safety. The Power Unit performs all of the following functions:

- Battery charging from the PV array.
- Battery charging from the utility.
- Grid-tied sell back output.
- Stand-alone backup AC output.
- Automatic utility disconnect.

## THEORY OF OPERATION

The Power Unit utilizes a higher voltage battery interface and PV interface. The higher voltage battery interface allows the use of a higher voltage Energy Storage Unit for increased efficiency and improved load response. The wide-range PV interface voltage accommodates a large variety of PV module arrangements, and accepts the reduced DC wiring and combination that results from the use of the prefabricated high voltage PV array.

Rather than storing energy at a low voltage and then boosting the full output power during stand alone or backup operation, this unit boosts the PV voltage as the PV generated power enters the Power Unit, and energy is stored at the higher voltage. Higher voltage energy storage allows direct DC to AC power conversion without the relatively high losses of the full power voltage boost stage or 60 Hz transformer required with low voltage storage systems. Also, higher DC input voltage means proportionately lower input currents. Lower input currents translate to lower copper losses, lower semiconductor conduction losses and smaller wire and terminal sizes. Additionally, from a dynamic performance perspective, having the energy storage source (batteries) directly across the DC bus provides for excellent transient response during output load surges due to motor starts.

### RESIDENTIAL POWER UNIT FEATURES

- Stand alone or grid tied operation
- 12kW continuous / 19.2kW peak power
- High conversion efficiency >96% @ full load
- Single enclosure system integrated design:
  - AC Line and Load Breakers
  - Auto Transfer Contactor
  - PV Max Power Tracker
  - Split Phase Inverter
- Weatherproof, tamperproof enclosure
- Two independently regulated 120Vac outputs
- Configurable as 120V @ ”200A” or 240V @ “100A”
- Low noise fan with continuously variable speed control
- Remote display showing hours of battery capacity remaining at current usage rate.
- Designed for use with the Xantrex Energy Storage Unit

Xantrex has completed the design and testing of a Power Unit for residential off-grid and back-up power applications. A new, consolidated Power Unit which performs all of the functions necessary for a versatile, integrated stand alone and residential backup power supply was shown to be commercially viable. The innovative packaging of the Power Unit was designed for outdoor deployment, ease of installation and for user safety (Figure 3).

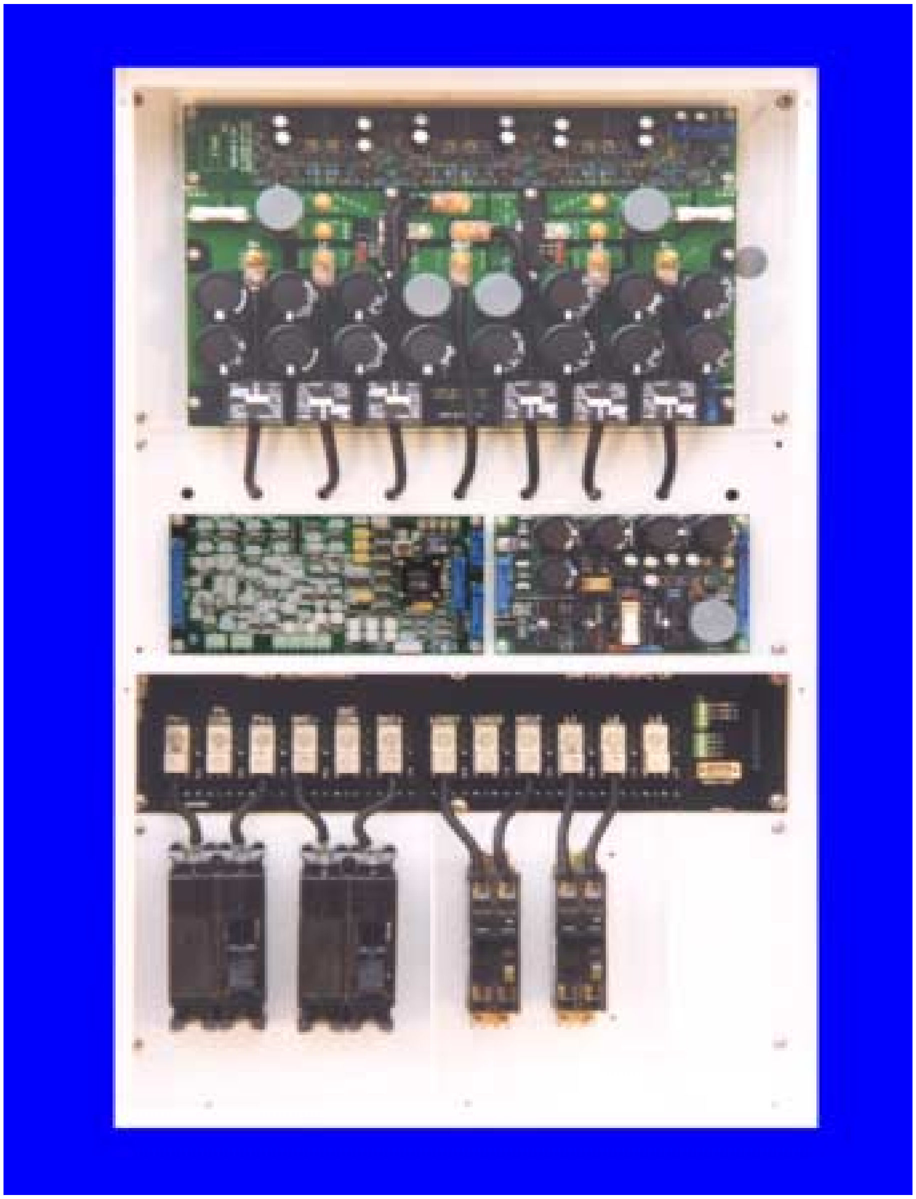

**Figure 3. Power Unit with Front Panel Removed**

## POWER UNIT PERFORMANCE

The Power Unit has been subjected to a series of performance tests. These tests have simulated typical use of this equipment for PV applications. The prototypes have been evaluated for their structural integrity, electrical performance, reliability, cost, and manufacturability.

- Testing of the prototype Power Unit demonstrated total harmonic distortion (THD) to be only 0.9%, operating at the full rated power level of 6.2 Kilowatts per AC line. Output current measurements were recorded on a Fluke Model 41 Power Analyzer (Figures 4, 5 and 6).

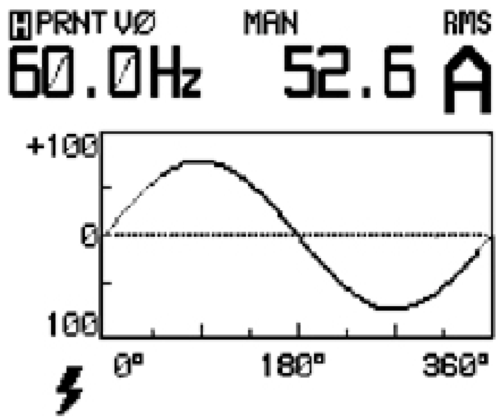


**Figure 4.**
**Power Unit Output Current Waveform**

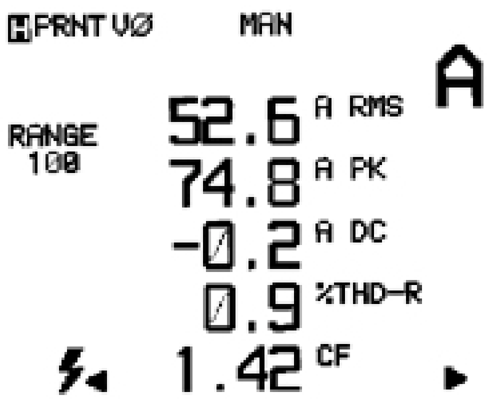


**Figure 5.**
**Power Unit Output Current Data**

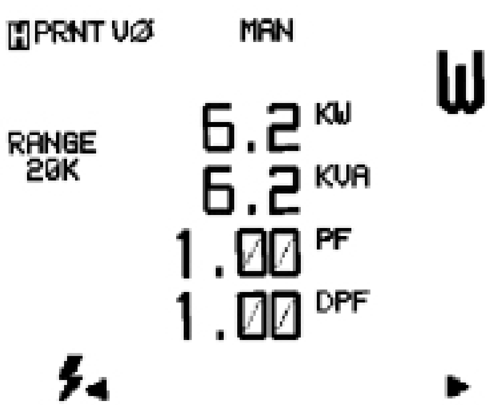


**Figure 6.**
**Output Power Per Line**

- Measurement of the total harmonic distortion at power levels of 30% to 100% of rated output power on the output shows that the THD remains under 2% within this entire range (Figure 7).

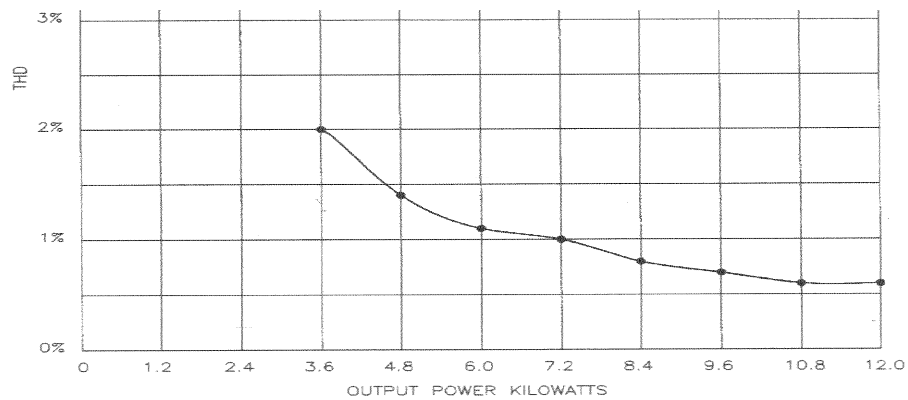


**Figure 7. Power Unit Output Current Distortion – 30% to 100% Load**

- A power conversion efficiency of 96% has been achieved, at power levels of 30% to 100% of rated output power. Efficiency was measured utilizing a Voltec Model 3000A power analyzer and a set of current shunts calibrated to 0.1% accuracy (Figure 8).

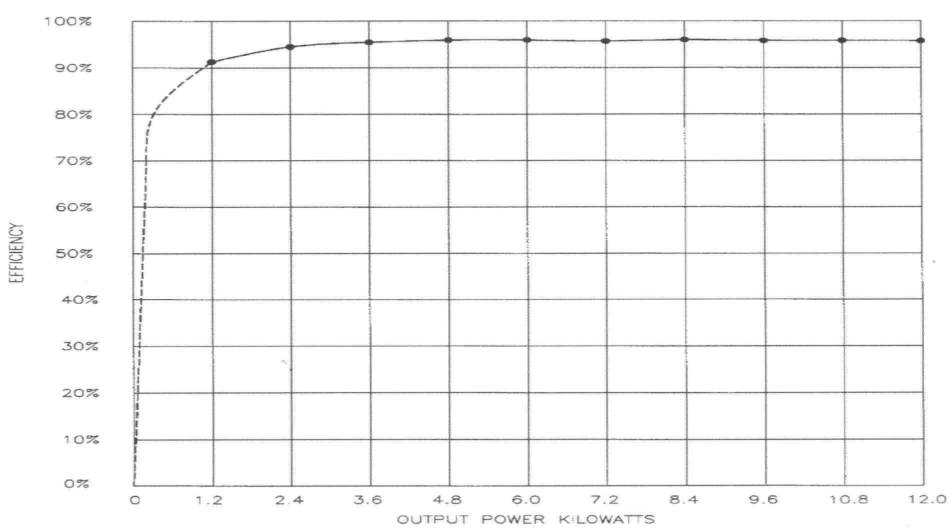


**Figure 8. Power Unit Efficiency**

## TASKS 3 AND 6. ENERGY STORAGE UNIT DEVELOPMENT AND OPTIMIZATION

Xantrex Technology Inc. has completed the design, testing and UL listing on the Energy Storage Unit (ESU).

A design for the ESU was first developed for use with the Power Unit. Rather than the leaving the system designer or homeowner to buy and house batteries and design a custom system, the Energy Storage Unit was planned with integral batteries, control electronics, and communication with the Power Unit.

A complete design was then created for the ESU and two prototypes were manufactured. The innovative packaging of the ESU was designed for outdoor deployment, ease of transportation, ease of installation, and for user safety. The ESU also employs a "smart" temperature regulation scheme, which uses the thermal mass of the batteries in conjunction with the tailored heat transfer characteristics of the integrated environmental enclosure to regulate the battery cell temperatures for optimum battery lifetime.

### THEORY OF OPERATION

Common backup battery supply voltages are limited to 48 Volts DC. The Xantrex solution enables the use of supply battery voltages of 450 Volts DC. Higher voltage energy storage allows direct DC to AC power conversion without the relatively high losses of the voltage "boost" stage required with low voltage storage systems. Also, higher DC input voltage means proportionately lower input currents. Lower input currents translate to lower copper losses, lower semiconductor conduction losses and smaller wire and terminal sizes. Additionally, from a dynamic performance perspective, having the energy storage source (batteries) directly across the DC bus provides for excellent transient response during sudden output load changes.

Traditionally, series strings of batteries had severely compromised lifetimes and low recharge energy capacity. These technical difficulties were overcome and this higher voltage series battery string topology was made commercially viable through the development of an innovative, low cost, microprocessor-based Active Charge Control circuit. This "smart" circuit actively balances the charge of all the individual battery components in the series string, maintaining the full battery recharge rate and lifetime.

These technical advances of the charge balance circuit and the integrated environmental enclosure enabled the use of Valve-Regulated Lead-Acid (VRLA) batteries within the ESU. VRLA batteries were chosen because they are safe to handle, have deep-cycle capability, and are maintenance-free. Traditional flooded lead-acid batteries require regular maintenance, and they are not well suited to the factory assembly environment due to restrictions in shipping and handling, since they can spill corrosive acid and vent dangerous hydrogen. Likewise, the use of gelled electrolyte batteries was avoided due to severe limitations in their power output load range and recovery (Figure 9).

## ENERGY STORAGE UNIT FEATURES

- 13kW-hour energy storage capacity
- Maintenance free batteries
- Easy to parallel for added capacity
- Load break safety switch disconnect
- Low current, higher voltage design
- Weatherproof, tamperproof enclosure
- Insulated enclosure with smart temperature control
- Active overcharge protection


**Figure 9. Energy Storage Unit with Top and Side Panels Removed**

## TASK 4. PV ARRAY OPTIMIZATION

The objective of this task was to develop the final design and to demonstrate a modular, UL-listed residential PV Array with a direct materials and labor cost (exclusive of PV module cost) below $4.00 per square foot. After the successful implementation of the prototype arrays, the design was optimized to utilize standard metal shapes and reduce parts count while maintaining the timesavings and simplicity of the prototype modular design. The cost to install this optimized array is as low as $3.79 per square foot.

The prototype array design demonstrated how the pre-fabricated PV array can simplify the site-specific design and installation time for a rooftop PV system. The cost of the installation, however, was $11.76 per square foot, due to the expense of the custom fabricated materials utilized. The cost goal for this program was $4.00 to $5.00 per square foot for the PV array installation materials and labor (excluding the PV panels.) Quotations for material for a volume of 500 systems reduced the cost only to approximately $8.50 per square foot.

**Figure 10. Final Design – Runners Attached to Roof**

To achieve the cost goals, material cost was reduced by incorporating commercially available strut channel runners in place of the custom fabricated ones. The runners now are placed vertically on top of the roof surface and rafters. This design eliminates the standoff assemblies associated with horizontal structural mounting that were required to permit water run off and avoid vegetation build up. A commercially available L-bracket is placed on the lower end of each runner to facilitate placement of the PV panels.

The PV panelization process was extended to incorporate up to four modules (thin film or crystalline), maintaining ease of assembly and handling, while enabling a greater degree of module array pre-wiring to be applied in the factory environment. This reduces the required number of runners and simplifies the field wiring requirements.

**Figure 11. Final Design with Three PV Panels in Place**

This entire PV array design now utilizes only two fabricated components. The modules are assembled into panels by attachment to a rail, which is fabricated from ASTM 653 Grade 50 structural steel. This rail is manufactured in a single operation, so that the cost of fabrication for the rail is only slightly more than that of purchasing a standard shape. Depending on the module configuration, either C-rails or Z-rails are utilized, in order to place the outer lip of the rail at the edge of the panel. A simple C-clamp assembly provides ease of PV panel placement and positional adjustment while maintaining maximum hold down strength to the strut channel runners. (See Figures 10 and 11.)

This design has been finalized and is in production. Documentation for the fabrication and assembly of the PV panel is shown in Figure 12.

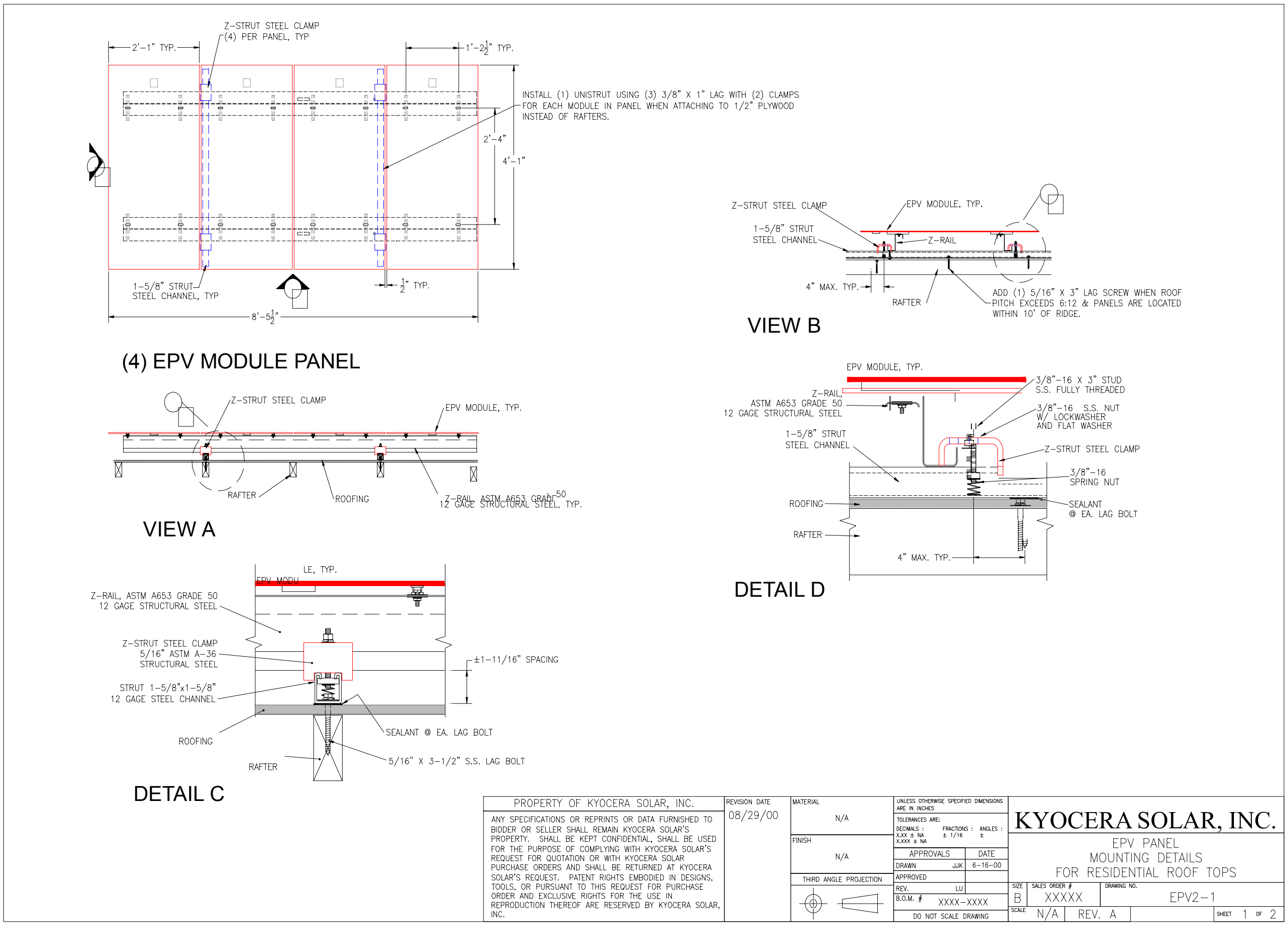


**Figure 12. Engineering Documentation of PV Panel**

The installation cost for the PV array has been substantially reduced with this design. Under the most favorable conditions, typically a single story dwelling with no roof obstructions and the electrical grid tie-in located on the wall under the roof top PV array, the cost of installation material and labor, excluding the PV modules, has been documented to be as low as $3.79 per square foot. More complex installations, such as two-story dwellings, and multiple roof angles, have had installation costs of $4.00 to $6.00 per square foot.

This system has been adapted to three different commercially available PV modules:

- Kyocera Solar Model KC120
- Siemens Solar Model SP-75
- EPV Model EPV40

## TASK 7. OPERATING MANUALS

A consumer-oriented installation manual has been created for the new PV system. This manual is available in Appendix 1.

# 2. ECONOMIC ANALYSIS

## 2.1. POWER UNIT COST

The manufacturing and assembly costs of the Power Unit have been finalized. The cost, based on a production run of 100 units, is $4060.28 for a 12 kilowatt Power Unit, or $0.34 per watt as detailed in Table 1.

| Qty | P/N | Title | Parts | Parts Cost | Labor | Parts + Labor |
|---|---|---|---|---|---|---|
| | A05000 | Assembly, 12KW Inverter | | | $120.00 | $120.00 |
| 1 | B05100A | Assembly, PCB, Power Bridge Board | $534.68 | $534.68 | $60.00 | $594.68 |
| 1 | B05200A | Assembly, PCB, Contactor Board | $159.58 | $159.58 | $7.00 | $166.58 |
| 1 | B05300A | Assembly, PCB, PV Combiner Board | $106.45 | $106.45 | $12.00 | $118.45 |
| 1 | B05400A | Assembly, PCB, Capacitor Board | $42.45 | $42.45 | $4.00 | $46.45 |
| 1 | B05500B | Assembly, PCB, Control Board | $131.20 | $131.20 | $145.00 | $276.20 |
| 1 | B05550A | Assembly, PCB, Operator Int. Board | $19.94 | $19.94 | $9.00 | $28.94 |
| 1 | B05600A | Assembly, PCB, Crowbar Board | $146.31 | $146.31 | $42.00 | $188.31 |
| 1 | B05650A | Assembly, PCB, Power Supply Board | $171.12 | $171.12 | $30.00 | $201.12 |
| 1 | B05700A | Assembly, PCB, Drive Board | $146.46 | $146.46 | $32.00 | $178.46 |
| 32 | B1-1032012 | Screw, Pan Head | $0.05 | $1.57 | | $1.57 |
| 2 | FAN-PQ24B4 | Fan, 24 V dc | $48.00 | $96.00 | | $96.00 |
| 1 | FLTR-PF4550 | Filter, air | $12.35 | $12.35 | | $12.35 |
| 10 | GR-34516 | Grommet, Rubber | $0.27 | $2.69 | | $2.69 |
| 2 | IC-LM35CAZ | IC,Temperature Sensor | $10.00 | $20.00 | | $20.00 |
| 1 | J1-TA2 | Lug, Box | $0.58 | $0.58 | | $0.58 |
| 1 | J2-1DB | Teminal Block | $32.90 | $32.90 | | $32.90 |
| 1 | J2-1SB | Teminal Block | $5.86 | $5.86 | | $5.86 |
| 6 | J4-IDC20 | Connector, IDC | $1.28 | $7.69 | | $7.69 |
| 6 | J4-IDC40 | Connector, IDC | $1.97 | $11.84 | | $11.84 |
| 1 | K5-192DC60A-S | Breaker | $250.55 | $250.55 | | $250.55 |
| 1 | K5-QOU2100 | Breaker | $40.00 | $40.00 | | $40.00 |
| 1 | M05001A | Enclosure | $400.00 | $400.00 | | $400.00 |
| 1 | M05002A | Enclosure Door | $0.00 | $0.00 | | $0.00 |
| 3 | M05003A | Barrier | $17.97 | $53.91 | | $53.91 |
| 4 | M05004A | Transformer Mounting Cup, Small | $0.00 | $0.00 | | $0.00 |
| 4 | M05005A | Transformer Mounting Cup, Large | $0.00 | $0.00 | | $0.00 |
| 1 | M05006A | Heatsink | $60.83 | $60.83 | $37.00 | $97.83 |
| 1 | M05007A | Panel, Magnetics Access | $249.91 | $249.91 | | $249.91 |
| 1 | M05008A | Panel, Heatsink Access | $49.00 | $49.00 | | $49.00 |
| 1 | M05009A | Panel, Bottom Access | $56.74 | $56.74 | | $56.74 |
| 1 | M05010A | Panel, Top Access | $60.53 | $60.53 | | $60.53 |
| 1 | M05011A | Bracket, Capacitor Assembly | $63.00 | $63.00 | | $63.00 |
| 2 | M05012A | Hood | $45.90 | $91.80 | | $91.80 |
| 1 | M05013A | Filter Screen Assembly | $0.00 | $0.00 | | $0.00 |
| 32 | N1-1032NI | Nut, Nylon Insert | $0.06 | $1.98 | | $1.98 |
| 4 | SO3-FF103204375GA | Standoff | $0.39 | $1.56 | | $1.56 |
| 4 | SO3-FF1032075GA | Standoff | $0.52 | $2.08 | | $2.08 |
| 4 | SO3-MF1032012GA | Standoff | $2.05 | $8.20 | | $8.20 |
| 4 | SO3-MF1032100GA | Standoff | $0.02 | $0.06 | | $0.06 |
| 4 | SO4-FF08320875IGA | Standoff | $0.91 | $3.64 | | $3.64 |
| 4 | SO4-FF10321625IGA | Standoff | $1.50 | $6.00 | | $6.00 |
| 10 | WR1-6HYP | Wire, single conductor | $0.05 | $0.53 | | $0.53 |
| 5 | WR4-20GRY | Cable, Flat ribbon | $0.15 | $0.73 | | $0.73 |
| 5 | WR4-40GRY | Cable, Flat ribbon | $0.31 | $1.55 | | $1.55 |
| 2 | X05090 | Inductor, Primary Line Filter | $120.00 | $240.00 | | $240.00 |
| 2 | X05091 | Inductor, Line Filter, Secondary | $60.00 | $120.00 | | $120.00 |
| 2 | X05092 | Balun | $50.00 | $100.00 | | $100.00 |
| 2 | X05093 | Boost Inductor | $25.00 | $50.00 | | $50.00 |
| | | **Total Parts** | | **$3,562.28** | | |
| | | **Total Labor** | | | **$498.00** | |
| | | **Total Parts and Labor for 1 unit** | | | | **$4,060.28** |

**Table 1. Power Unit Direct Material and Labor Cost**

## 2.2. ARRAY COST

An objective of this project was to develop the final design and to demonstrate a modular, UL-listed residential PV Array with a direct materials and labor cost (exclusive of PV module cost) below $4.00 per square foot. The system that has been developed and demonstrated has a cost as low as $3.79 to $3.95 per square foot for installations with minimum complexity (see Table 2).

| MODULE TYPE | AREA OF MODULE | NUMBER OF MODULES | TOTAL AREA OF MODULES | TOTAL COST | NON-ARRAY COSTS | ARRAY COST | ARRAY COST PER SQU. FOOT |
|---|---|---|---|---|---|---|---|
| EPV40 | 8.51 | 60 | 511 | 2148 | 214.8 | 1933.20 | 3.79 |
| EPV40 | 8.51 | 100 | 851 | 3733 | 373.3 | 3359.70 | 3.95 |

**Table 2. Installation Cost, Exclusive of Module Cost**

# 3. CONCLUSIONS AND RECOMMENDATIONS

Utility Power Group (UPG), a wholly owned subsidiary of Kyocera Solar, Inc. and Xantrex Technology have completed design, testing and UL listing phases for an innovative integrated, low-cost residential photovoltaic (PV) power system with an energy storage capability. The component products of this system have been evaluated by UPG and Xantrex, for their structural integrity, electrical performance, reliability, cost, and manufacturability.

The goal of this subcontract has been to increase US domestic PV system production and installation capacity by creating a readily manufacturable product.

# 4. PERFORMANCE OBJECTIVES

As a result of this program, over 80 new PV arrays, utilizing developments from this program, have been installed on rooftops in the greater Sacramento metropolitan area.

The Power Unit and Energy Storage Unit (ESU) have been built and tested, and have met the technical goals set forth. The feasibility of such a system has been demonstrated. Unlike other PV systems which utilize a collection of discrete battery chargers, inverters, relays and switches, the Power Unit is designed to perform all of these functions within a single enclosure containing bi-directional power circuitry and a common control module. Likewise, the ESU further eliminates the need for a complex site-specific system design coordinating batteries and a battery housing with the electrical equipment.

The goal for the Power Unit, operating at the higher voltage from the Energy Storage Unit, was to achieve a conversion efficiency of greater than 94% at 100% of rated output power, with total harmonic distortion below 5%. The Power Unit prototype has exceeded this goal by achieving measured performance of 96% efficiency and total harmonic distortion under 2%, at power levels of 30% to 100% of rated output power.

## 4.1. ECONOMIC PERFORMANCE OBJECTIVES

Achievement of the overall goal of this is affected by the economic reality that the price of PV systems is prohibitive to many individuals and organizations that might otherwise want to have such systems installed. The original cost goals established for this product were achieved, as follows:

- PV Array Installation Costs
  The material and direct labor cost of installing the PV array has been reduced from \$7.00 to as low as \$3.79 per square foot, for a 2400W installation.

- Power Unit Production Costs
  The material and direct labor cost of producing the Power Unit has been reduced from \$0.67 to \$0.34 per Watt.

## 4.2. COMMERCIALIZATION POTENTIAL

The Power Unit and the Energy Storage Unit are now being evaluated for manufacturing per the Xantrex Product Creation and Support (PC&S) process. These two products must fit into existing Xantrex product technology platforms, replace an older product line or initiate a new product platform.

Since this development contract start date, the residential backup power market and the distributed energy markets have changed significantly. The way product is manufactured at Xantrex Technology has also changed. When the Model 5000 and 6000 are brought into production, there will more than likely be some changes dictated by current market conditions.

Going forward, there already exists a credible scenario for next generation products. There is a mandate within the Xantrex organization to design all new products by using a small number of functional hardware and software modules. The next generation Model 5000, Power Unit, for example, would consist of three functional blocks, that are used in other products as well; two half-bridge modules, one DC to DC max power tracker and one remote display.

The advantages of this design philosophy are improved product reliability, lower product costs and easier application of mass production manufacturing techniques.

## 4.3. BENEFITS

The benefits from this program include increased employment and reduced pollution.

- The average residential rooftop PV power system installed in Sacramento, California will produce 2,890 kWh of electricity per year, and eliminate 3,583 pounds of $CO_2$ and 1 pounds of $NO_X$ emissions in the first year.

- The products designed under this contract are being built in the United States.

Xantrex Technology Inc in Livermore, CA occupies approximately 10,000 square feet of light industrial space. The facilities include manufacturing assembly and test, an engineering development laboratory, and engineering and administrative office space.

Utility Power Group (UPG), a wholly owned subsidiary of Kyocera Solar, Inc. is based in Sacramento, California. UPG provides Solar photovoltaic power systems to government, industrial, commercial and residential customers that desire a source of pollution-free and reliable electrical power. They are the largest integrator of grid-support PV systems in the U.S.

# GLOSSARY

Balance of System (BOS): A photovoltaic power system, excluding the technology and cost of the photovoltaic modules. Often referred to as BOS cost, which is the cost of installation labor and direct materials, excluding the cost of the photovoltaic modules.

Efficiency: The ratio of useful output power to the input power delivered to a device. The higher the efficiency of an inverter, the less power is wasted.

Energy Storage Unit (ESU): A system-integrated component incorporating storage batteries with other system control and protection functions.

Grid-Support: A photovoltaic system that is connected to a centralized electrical power network. Also, Utility Interactive.

Hybrid PV System: A photovoltaic system which automatically converts from grid support mode to battery backup mode, based on a logical interpretation of data including battery charge state, grid availability, and solar irradiance.

Photovoltaic (PV) Array: A group of photovoltaic modules wired together to produce a specific amount of power.

Photovoltaic (PV) Cell: A semi-conductor device that converts light directly into electricity.

Photovoltaic (PV) Module: A number of solar electric cells wired together to form a unit, or a thin-film solar cell, in a sealed frame of convenient size.

Power Unit: A system-integrated component incorporating an inverter with other system control and protection functions.

System Integrated: Used to describe a component that combines the functions of several commonly separate devices, into one component.

Total Harmonic Distortion: The ratio of a wave's harmonic content to its fundamental component, expressed as a percentage. It is a measure of the extent to which a waveform is distorted by harmonic content. It is usually expressed as current or voltage "total harmonic distortion" or “THD”.

| REPORT DOCUMENTATION PAGE | | | *Form Approved* *OMB NO. 0704-0188* |
|---|---|---|---|
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503. | | | |
| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE<br>October 2002 | 3. REPORT TYPE AND DATES COVERED<br>Final Subcontract Report<br>December 18, 2001 | |
| 4. TITLE AND SUBTITLE<br>Development of a Fully Integrated PV System for Residential Applications, PVMaT5a Final Report, December 18, 2001<br>6. AUTHOR(S)<br>J. Oatman and R. West | | | 5. FUNDING NUMBERS<br>TA: PVP2.6101<br>CF: ZAX-8-17647-02 |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>UPG Division of Kyocera Solar, Inc.<br>Sacramento, California<br>480-948-8003<br>and<br>Xantrex Technology Incorporated<br>San Luis Obispo, California<br>805-543-4520 | | | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br>National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401-3393 | | | 10. SPONSORING/MONITORING AGENCY REPORT NUMBER<br>NREL/SR-520-32540 |
| 11. SUPPLEMENTARY NOTES<br>NREL Technical Monitor: Holly Thomas | | | |
| 12a. DISTRIBUTION/AVAILABILITY STATEMENT<br>National Technical Information Service<br>U.S. Department of Commerce<br>5285 Port Royal Road<br>Springfield, VA 22161 | | | 12b. DISTRIBUTION CODE |
| 13. ABSTRACT *(Maximum 200 words)* This report describes how both the Utility Power Group (UPG), a wholly owned subsidiary of Kyocera Solar, Inc., and Xantrex Technology Inc., have designed, assembled, and tested a new photovoltaic (PV) power system for residential rooftops to meet the goal of a readily manufacturable product that will increase US domestic PV power system production and installed capacity, by reducing the total installed cost and increasing the reliability of residential rooftop mounted PV power systems. A new factory pre-fabricated PV array system was developed, and 80 have been installed on the residential rooftops using standard metal parts. The direct material and labor cost of the array installation has been reduced to $3.79 per square foot for a 2400W installation. A modular, maintenance free, battery-based Power Unit and Energy Storage Unit (power conditioning and control) have also been developed. The design, fabrication, and testing have been completed for two prototypes of this system. These products have been evaluated for their structural integrity, electrical performance, reliability, cost, and manufacturability. The direct material and labor cost of the Power Unit has been reduced to $0.34 per watt. The 13 kW-hr Energy Storage Unit (ESU) has been UL listed. | | | |
| 14. SUBJECT TERMS: PV; manufacturer; balance-of-system (BOS); power unit; energy storage; system integrated; power conditioning inverter | | | 15. NUMBER OF PAGES<br>16. PRICE CODE |
| 17. SECURITY CLASSIFICATION OF REPORT<br>Unclassified | 18. SECURITY CLASSIFICATION OF THIS PAGE<br>Unclassified | 19. SECURITY CLASSIFICATION OF ABSTRACT<br>Unclassified | 20. LIMITATION OF ABSTRACT<br>UL |